

Ejector jet mill with external pressure

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Abstract. Jet mills are used to produce fine products in many industries. Spiral jet mills and fluidized bed jet mills are widely used. They differ in that the destruction of particles occurs as a result of the abrasion process. The use of impact ejector jet mills is limited by a relatively low consumable concentration of material. When the consumable concentration of the material increases the acceleration speed of particles and the material grinding degree decrease. To eliminate this disadvantage a new method and design of an ejector jet mill for fine grinding of bulk materials has been developed (patent of Russian Federation No. 2711252). The technological process occurs at excessive external pressure of the ejected gas. It is shown that it is feasible to increase the pressure at the beginning of the acceleration tube when the pressures ratio of the working and secondary gas is higher than the critical one. It increases the consumption concentration of bulk material and the acceleration speed of crushed particles. This allows reducing the specific energy consumption and increasing the grinding degree. Experimental studies have confirmed an increase in the consumption concentration by 1.6–1.9 times and an increase in the grinding degree by 1.3–1.7 times compared to a typical ejector jet mill.

1. Introduction

Jet grinding is a promising method for obtaining of fine materials being used in many industries where the quality of the finished product is of big importance. It is known that jet mills provide a relatively high purity of the finished product by chemical composition. This type of equipment uses the energy of compressed gas to accelerate and crush particles. Grinding occurs in a small volume with a high concentration of energy which is an advantage for the mechanical activation of materials. Having a large number of advantages jet mills are of both scientific and practical interest in the intensification of the grinding process [1, 2, 3].

Spiral jet mills and fluidized bed jet mills are widely used. They differ in that the main process of particle destruction is abrasion. Recent studies of fluidized bed jet mills are mainly aimed at modeling two-phase flows during grinding in a fluidized bed as well as the classification process, since this process affects the productivity and quality of the finished product [4, 5]. Studies of spiral mills are mainly aimed at modeling the particles movement in the grinding chamber and predicting the material grinding [6, 7]. The use of an impact ejector jet mills and countercurrent jet mills have not received the widespread due to abrasive wear and limited material concentration. In countercurrent jet mills the probability of particles collisions in jets with a low concentration is very low [2]. The papers [8, 9] present studies on optimization of the nozzle and acceleration tube in order to increase the particles velocity with a relatively low consumable concentration of solid particles for this type of mills.

The aim of this work is to increase the consumable concentration of the crushed material and the particles velocity in an ejector jet mill.



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2. Main part

Material grinding in jet mills occurs as a result of the impact of particles on the barrier or due to the collision of two counter streams of particles. The grinding degree of the material is determined by the speed of particle acceleration and the specific energy consumption depends on the consumption concentration of the material which is determined by the ratio [10]:

$$\mu = \frac{G_m}{G_g}, \quad (1)$$

where μ – consumption concentrations of material kg/kg; G_m – capacity by material, kg/s; G_g – mass gas consumption, kg/s.

It is known that increasing the material concentration can increase productivity and reduce specific energy consumption [11]. It is possible to increase the acceleration speed and consumption concentration by increasing the pressure at the beginning of the acceleration tube. Gas dynamics rules [12] state that the maximum pressure is at the end of the mixing chamber and at the beginning of the acceleration tube it is determined by the dependence:

$$P_3 = \frac{\alpha P_1 + P_2}{\alpha + 1}, \quad (2)$$

where P_3 – the total pressure at the beginning of the acceleration tube; α – the main geometric parameter of the ejector equal to the ratio of the areas of the output sections of the nozzles for the ejecting and ejected gases; P_1 – the total pressure before the nozzle of the ejecting gas; P_2 – the external pressure of the ejected gas.

For ejector jet mills the initial section of the acceleration tube is a mixing chamber so the main geometric parameter of the ejector is found from the equation:

$$\alpha = \frac{F_1}{F_3 - F_1} = \frac{d_1^2}{D_3^2 - d_1^2} = \left(\left(\frac{D_3}{d_1} \right)^2 - 1 \right)^{-1}, \quad (3)$$

where F_1 – sectional area of nozzle, m²; F_3 – sectional area of the acceleration tube, m²; d_1 – diameter of the critical section of the nozzle, m; D_3 – diameter of the acceleration tube, m.

In typical ejector jet mills the pressure of the ejected gas P_2 is equal to the atmospheric pressure P_a . Therefore, according to equation (2) the pressure P_3 at the beginning of the acceleration tube is limited and usually does not exceed 2.5 atm. Its increase by increasing α and P_1 is impossible due to blocking the ejector [13]. A scheme of a typical ejector jet mill with a graph of the total pressure P change along the length of the acceleration tube L_t is shown in figure 1.

To increase the pressure at the beginning of the acceleration tube P_3 a method has been developed (patent of Russian Federation No. 2711252 [10]). It differs in that the ejection is performed at an external pressure of the ejected gas above atmospheric pressure $P_2 > P_a$. At the same time the ratio of pressure in front of the nozzle and outside of the nozzle (P_1/P_2) must be greater than the critical one to keep supersonic gas velocity at the outlet of the nozzle, i.e. the condition [12]:

$$\Pi = \frac{P_1}{P_2} > \frac{P_1}{P_k} = \left(\frac{k+1}{2} \right)^{\frac{k}{k-1}} \approx 1.893, \quad (4)$$

where Π – the pressure ratio; P_k – critical gas pressure before the nozzle; k – the adiabatic coefficient (for air $k = 1.4$).

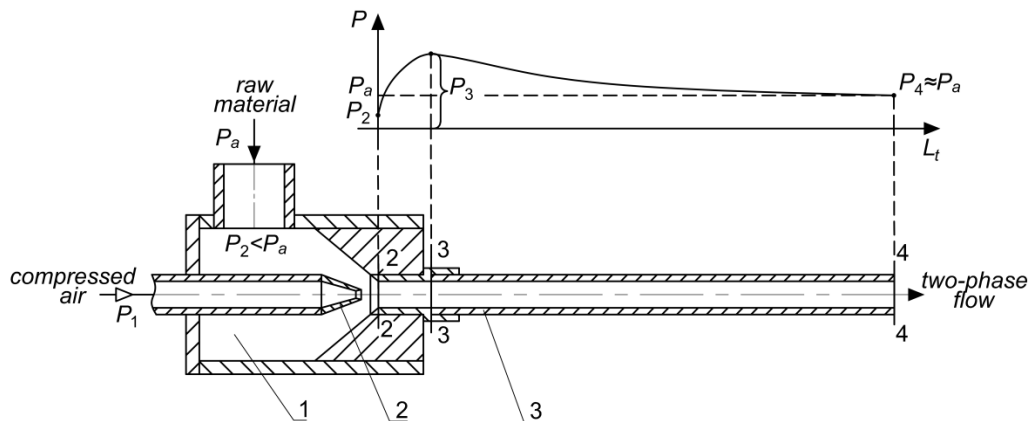


Figure 1. Typical ejector jet mill with a graph of the total pressure along the length of the acceleration tube:

1 – ejector chamber; 2 – the supersonic nozzle; 3 – acceleration tube; 2–2 – the acceleration tube beginning (the beginning of flows mixing in acceleration tube); 3–3 – the end of flows mixing (the beginning of two-phase flow acceleration); 4–4 – the acceleration tube end.

Figure 2 shows a scheme of an ejector jet mill with external pressure and a graph of the total pressure P change along the length of the acceleration tube L_t . Table 1 shows the calculations of the pressure P_3 and P'_3 at the beginning of the acceleration tube according for a typical ejector jet mill and an ejector jet mill with external pressure respectively.

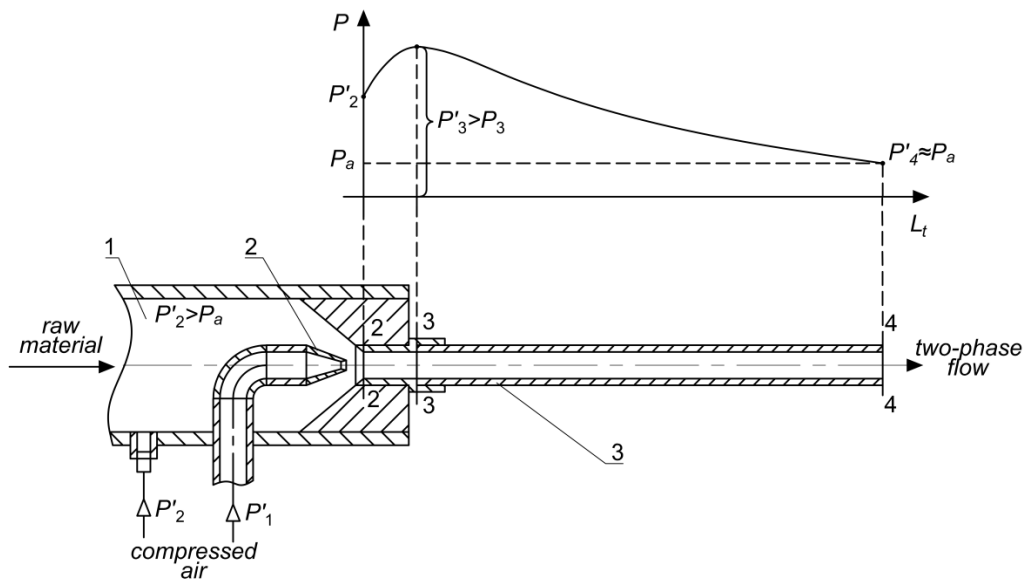


Figure 2. Ejector mill with external pressure and a graph of the total pressure along the length of the acceleration tube:

1 – ejector chamber; 2 – the supersonic nozzle; 3 – acceleration tube; 2–2 – the acceleration tube beginning (the beginning of flows mixing in acceleration tube); 3–3 – the end of flows mixing (the beginning of two-phase flow acceleration); 4–4 – the acceleration tube end.

Table 1. Dependence of the pressure at the beginning of the acceleration tube for a typical ejector P_3 and an ejector with an external pressure P'_3 at $P_1=7$.

D_3/d_1	α	P_3 , at	P'_3 , at
2.0	0.333	2.5	4.38
2.5	0.190	1.96	4.06
3.0	0.125	1.67	3.89

It follows from the presented data that at the same pressure P_1 of the working gas before the nozzle in the new mill the pressure at the beginning of the acceleration tube P'_3 is almost two times greater than in a typical jet mill [10].

3. Experimental research

To implement method mentioned above the installation of an ejector jet mill with external pressure was developed (patent of Russian Federation No. 2711252 [10]). The installation scheme is shown in figure 3.

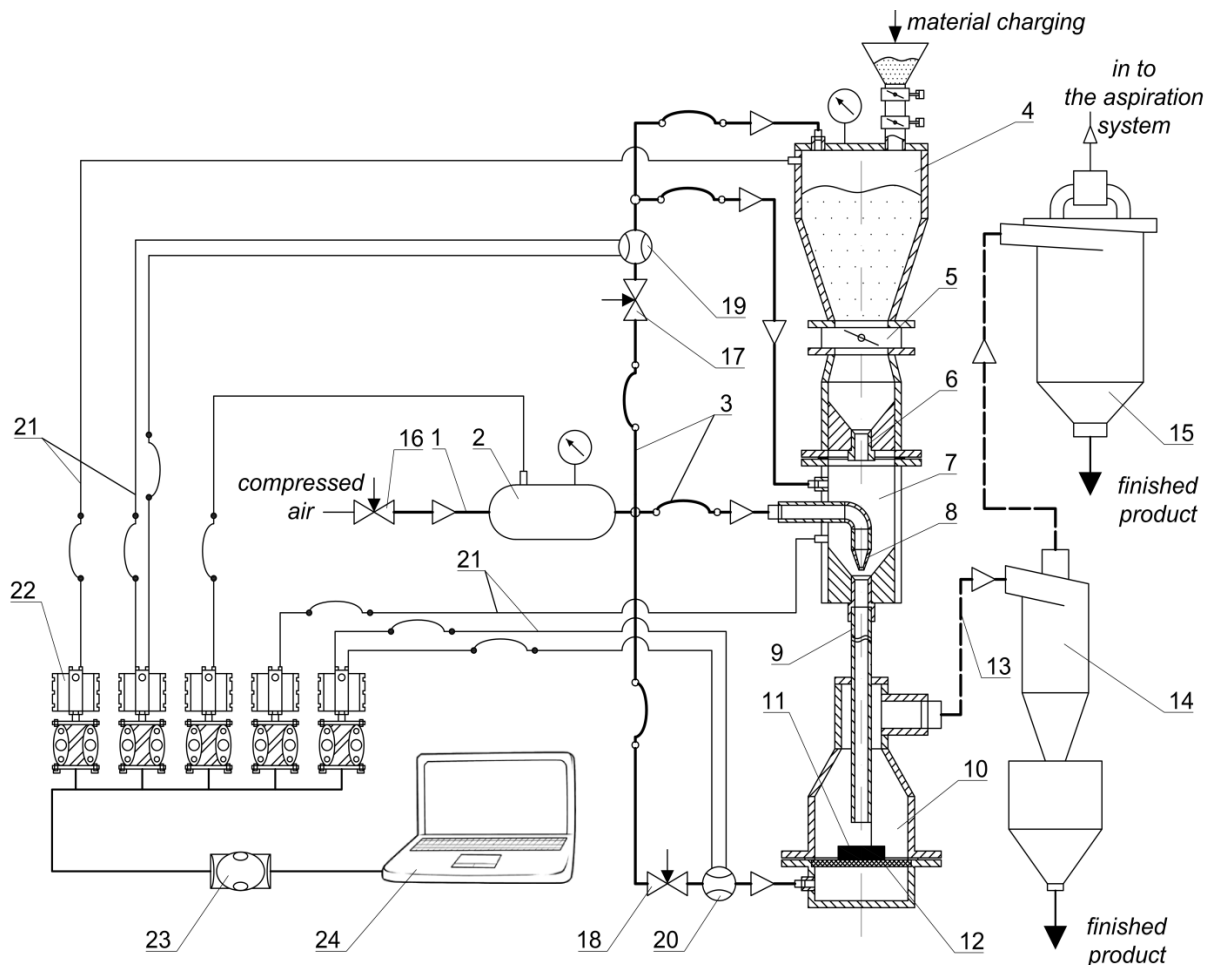


Figure 3. The installation scheme of the ejector jet mill with external pressure:

- 1 – compressed air sleeve; 2 – receiver; 3 – flexible pipelines; 4 – material hopper; 5 – rotary shutter; 6 – insert with a calibrated hole; 7 – ejector chamber; 8 – the supersonic nozzle; 9 – acceleration tube; 10 – grinding chamber; 11 – barrier; 12 – aerating grid; 13 – air pipes; 14 – cyclone; 15 – bag filter; 16, 17, 18 – ball valve; 19, 20 – standard diaphragm; 21 – pressure gauges; 22 – microprocessor sensors ‘Metran-100 DI’, ‘Metran-100 DD’; 23 – controller; 24 – PC.

Jet mill with an outer pressure works in the following way. Compressed air is piped through 1 to the receiver 2, where the full pressure of the working gas P_1 is maintained by the valve 16. Through pipelines 3 compressed air is supplied to the nozzle 8, to the hopper 4, to the ejector chamber 7 and under the aerating grid 12. With the help of a tap 17 and a standard diaphragm 19, the required flow rate of the ejected air G_2 is set, and an external pressure P_2 is created in the hopper 4 and the ejector chamber 7. With the help of a tap 18 and a standard diaphragm 20 the necessary air flow G_3 is set for aeration of the material in the grinding chamber 10. Then the rotary shutter 5 opens and through the calibrated hole 6 the crushed material flows through the ejector chamber to the acceleration tube 9 where the material is accelerated. After impacting the barrier 11 the crushed material is removed to the

cyclone 14 through the pipe 13. Sanitary air cleaning is carried out in a bag filter 15. Operating pressure P_1 and external pressure P_2 as well as pressure differences are recorded through pulse tubes 21 by microprocessor pressure sensors 22. Data via the controller 23 are recorded in real time on a PC 24. Gas consumption G_1 is calculated according to the standard method [14, 15].

Comparative tests of a new design mill (JMEP) and a typical ejector mill (JM) were carried out. For grinding two materials were used, namely quartz sand with density $\rho_t = 2700 \text{ kg/m}^3$, bulk density $\rho_n = 1965 \text{ kg/m}^3$, an average particle size of $d_{50} = 280 \text{ }\mu\text{m}$ and feldspar with density $\rho_t = 2630 \text{ kg/m}^3$, bulk density $\rho_n = 1590 \text{ kg/m}^3$, the average particle size $d_{50} = 180 \text{ }\mu\text{m}$.

Granulometric compositions of materials after one grinding cycle are shown in table 2. As follows from the data presented the grinding degree as a result of a single impact for a mill with external pressure is higher. So, for quartz sand the average particle size and grinding degree in JM: $d_{50} = 126.96 \text{ }\mu\text{m}$, $i = 2.21$; in JMEP: $d_{50} = 74.99 \text{ }\mu\text{m}$, $i = 3.73$. The same characteristics for feldspar in JM: $d_{50} = 73.60 \text{ }\mu\text{m}$, $i = 2.45$; in JMEP: $d_{50} = 55.31 \text{ }\mu\text{m}$, $i = 3.25$. Thus, the use of an ejector jet mill with external pressure allowed to increase the grinding degree of quartz sand by 1.7 times and the grinding degree of feldspar by 1.3 times compared to a typical ejector jet mill.

Table 2. Granulometric compositions of grinding products in jet mill with external pressure (JMEP) and a typical ejector jet mill (JM).

Sieve	Quartzsand (JM)			Quartzsand (JMEP)			Feldspar(JM)			Feldspar(JMEP)		
$X, \mu\text{m}$	$R, \%$	$D, \%$	$r, \%$	$R, \%$	$D, \%$	$r, \%$	$R, \%$	$D, \%$	$r, \%$	$R, \%$	$D, \%$	$r, \%$
630	1.11	98.89	1.11	0.10	99.90	0.10	0.00	100.0	0.00	0.00	100.0	0.00
400	5.97	94.03	4.85	1.42	98.58	1.32	2.10	97.90	2.10	0.51	99.49	0.51
315	10.11	89.89	4.15	2.84	97.16	1.42	4.61	95.39	2.51	1.62	98.38	1.11
200	27.91	72.09	17.80	12.07	87.93	9.23	15.03	84.97	10.42	9.63	90.37	8.00
160	39.94	60.06	12.03	19.88	80.12	7.81	22.75	77.25	7.72	15.60	84.40	5.98
100	61.88	38.12	21.94	40.06	59.94	20.18	39.58	60.42	16.83	30.19	69.81	14.59
63	74.12	25.88	12.23	55.17	44.83	15.11	53.51	46.49	13.93	43.57	56.43	13.37
40	84.73	15.27	10.62	71.1	28.90	15.92	69.64	30.36	16.13	61.30	38.70	17.73
0	100.0	0.00	15.27	100.0	0.00	28.90	100.0	0.00	30.36	100.0	0.00	38.70

The operating parameters of mills for a single grinding cycle of quartz sand and feldspar are shown in table 3.

Table 3. Operating parameters of ‘JM’ and ‘JMEP’ mills for a single grinding cycle.

Material	m, kg	t, s	$G_m, \text{kg/s}$	P_1, MPa	P_2, MPa	$G_1, \text{kg/s}$	$G_2, \text{kg/s}$	$\mu, \text{kg/kg}$
Quartzsand(JM)	1.000	32	0.0312	0.5084	—	0.0283	—	1.104
Quartzsand(JMEP)	2.000	43	0.0465	0.5804	0.2328	0.0183	0.0076	1.796
Feldspar (JM)	0.800	30	0.0267	0.5017	—	0.0280	—	0.952
Feldspar (JMEP)	2.000	45	0.0444	0.5621	0.2357	0.0178	0.0073	1.771

It is seen from the presented data that the consumption concentration μ in an ejector jet mill with external pressure is 1.6 times greater when grinding quartz sand and 1.9 times greater when grinding feldspar compared to a typical ejector jet mill.

Also experiments were carried out in which the consumption concentration in an ejector jet mill with external pressure was increased by 3.0 times in comparison with a typical ejector jet mill when grinding quartz sand and by 4.0 times when grinding feldspar, and these mills showed quite similar degrees of material grinding.

4. Conclusions

A new method of jet grinding and the design of an ejector jet mill with external pressure is proposed (patent of the Russian Federation No. 2711252 [10]). This method allows increasing the pressure at the beginning of the acceleration tube due to external pressure. A higher pressure at the beginning of the acceleration tube allows increasing the consumption concentration of bulk material, and thus reducing the specific consumption of compressed air and increasing productivity. In addition, the

grinding degree of the material increases by boosting the acceleration speed of crushed particles which also contributes to the rise of productivity. At the same time to keep supersonic gas velocity at the outlet of the nozzle the ratio of pressures in front of the nozzle and outside of the nozzle must be greater than the critical one, i.e. the condition $P_1/P_2 > 1.1893$ must be met. Experimental studies of an ejector jet mill with external pressure showed an increase in the grinding degree of quartz sand by 1.7 times and grinding degree of feldspar by 1.3 times compared to a typical ejector jet mill. The consumption concentration increased by 1.6 times when grinding quartz sand and 1.9 times when grinding feldspar. Thus, using an ejector jet mill with external pressure allows increasing productivity and reduce the specific consumption of compressed air.

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